

The State of High Energy Physics + Hints of "New Physics"

A Brief Survey

Outline

1. Where are we now?
2. Outstanding Problems + Theoretical Speculations
3. Some "Hints" of "New Physics"
4. Experimental Frontiers
5. Outlook

1. Where are we now?

Standard Model = Scientific Triumph of 20th Century

"Symmetry Dictates Dynamics"

Poincaré Inv.

$\langle \text{Isospin, mass} \rangle$
general
coor.
inv

Gravity

SUSY?

Extra Dim.?

$SU(3)_c \times SU(2)_L \times U(1)_Y$

gluons, W^\pm , Z , γ

+ 3 fermion gen.

$\lambda(\phi^2 - v^2/\Lambda^2)^2$ Higgs
Sector

$v \approx 250 \text{ GeV}$

Scale of EW Sym. Br.

Is that all there is?

25 Years of Discovery + Confirmation!

$c, \tau, b, t, \nu_\tau, W^\pm, Z$, gluons (QCD = Perfect theory)

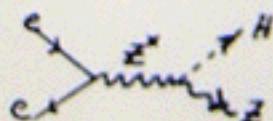
Precision EW Studies to $\pm 0.1\%$!! (Quantum Loops Probed)

FONC, CP, ... ν -osc. !

No Big Surprises? ($\tau_b, m_\tau, m_b \neq 0, \theta_W \approx 45^\circ, \dots$)

Where is the Higgs Scalar?

LEP II $e^+e^- \rightarrow ZH$



$m_H \gtrsim 113 \text{ GeV}$
(Hott at $\approx 115 \text{ GeV}$)

<u>Elementary Particles</u>	<u>Mass (GeV)</u>
1st generation { τ , e, u, d	see below 0.51×10^{-3} 5×10^{-3} 9×10^{-3}
2nd generation { γ_H , μ , c, s	see below 0.106 1.35 0.175
3rd generation { ν_T , τ , t, b	see below 1.777 <u>174.3 ± 5.1</u> ! Why? 4.5
Gauge Bosons { γ , W^\pm , Z, Gluons	0 <u>80.448 ± 0.034</u> ! <u>91.187 ± 0.002</u> 0
Scalar { H ?	<u>$113 < m_H < 212$ (800)</u> Where is the Higgs?
Neutrino Osc.	$ m_{\nu_3}^2 - m_{\nu_2}^2 \simeq 3 \times 10^{-3} \text{ eV}^2$ Super K $ m_{\nu_2}^2 - m_{\nu_1}^2 \sim 5 \times 10^{-5} \text{ eV}^2$ SNO + Super K (LMA) (Kamland) $\theta_{32} \sim 45^\circ$, $\theta_{21} \sim 27^\circ$, $\theta_{13} \lesssim 9^\circ$, $S \simeq ?$, ρ

2. Outstanding Problems \rightarrow Theoretical Speculations

i) Origin of EW Sym. Br. + Mass Generation

Fundamental Higgs? \rightarrow SUSY $\rightarrow h, H^0, A, H^\pm$ - sparticles

Strong Dynamics?: Technicolor, $t\bar{t}$ condensate...

Large Extra Dim? $10^{17} \text{ cm}?$

ii) Pattern of Fermion Masses, Mixing + CP (Flavor Problem)

Multi-Higgs + Sym (Mass Matrix Gymnastics)

Extended Technicolor

Not Addressed by SUSY (Except Heavy Top)

iii) Dark Matter \rightarrow Energy

Neutrinos? $m_\nu \sim 1 \text{ eV}$

LSP (lightest susy part): Neutralino, Smeutino

iv) Baryogenesis

New CP (eg. SUSY Phases)

v) Origin of Parity Violation, 3Gen, Gauge Sym. ...

Extra Dim., Superstrings ...

Answers will require "New Physics"

But at 1.1 - 1.2 TeV

3. Some "Hints" of "New Physics" (Not Inclusive)

Z pole leptonic asym. $\sin^2 \theta_W^{\text{eff}} = 0.231/4 \pm 0.00020$ (LEP II + LEP)

LEP II + Tevatron? $m_W = 80.448 \pm 0.034 \text{ GeV}$

Muon Anomalous Mag. Moment $g_\mu^{\text{exp}} - g_\mu^{\text{th}} = 426 \pm 151 \pm 67 \times 10^{-11} \text{ (C)}$

$b \rightarrow s\gamma$ $BR(b \rightarrow s\gamma)^{\text{th}} = 3.71 \pm 0.30 \times 10^{-4}$
 $BR(b \rightarrow s\gamma)^{\text{exp}} = \frac{1.96}{0.75} \pm 0.35 \times 10^{-4}$
 $0.35 \pm 0.35 \pm 0.30 \times 10^{-4}$ (C)

i) $\alpha, G_\mu, m_2 \xrightarrow[m_t, m_W]{} \sin^2 \theta_W^{\text{eff}}, m_W, P(Z \rightarrow l^+l^-) \dots$
 loops
 or "New Physics" $m_b^t, m_W^t, m_W^H, m_Z^H, m_W^Z \dots$

Natural Relation: $\sin^2 \theta_W^0 = \frac{e_0^2}{g_0^2} = 1 - (m_W^0/m_q^0)^2$

Global Fits $\rightarrow m_W \approx 98 \text{ GeV}$ $< 212 \text{ GeV}$ 95% CL
All Data

LEP II $\rightarrow m_W > 113 \text{ GeV}$ (No Conflict)? LEP II
SUSY

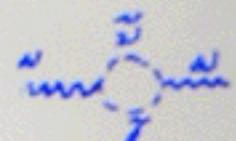
LEP $A_{FB}(Z \rightarrow b\bar{b})$ gives large $\sin^2 \theta_W^{\text{eff}} \approx 3.68$ dev from loop

without it $m_W \approx 40 \text{ GeV}$, $< 110 \text{ GeV}$ Conflict? Or Nearly

The 2 most precise measurements: $\sin^2 \theta_W^{\text{eff}}$ (leptonic) & M_W
suggest

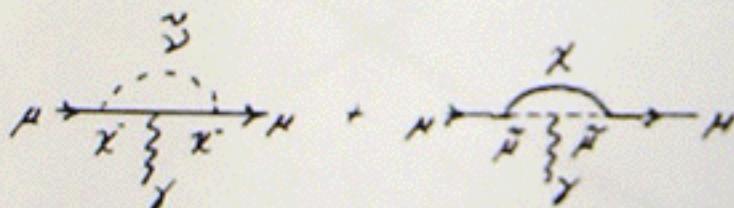
- 1) Very light Higgs $\sim 40 \text{ GeV}$ (ruled out)
- 2) Heavier top $\gtrsim 180 \text{ GeV}$
- 3) "New Physics"

example of "New Physics" (Altarelli, Corraffios, Giudice
 Gambino, Ridolfi)

Light Sneutrinos & Gauginos! 

$\text{Sneutrinos} \lesssim 80 \text{ GeV}$ $\text{Sleptons} \sim 115 \text{ GeV}$ $\text{light } \tilde{\chi}_1^\pm, \tilde{\chi}_2$	$\left. \begin{array}{c} \text{Tevatron} \\ p\bar{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2 \rightarrow \text{isolated leptons} \end{array} \right\}$
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(i) Muon Anomalous Magnetic Moment - SUSY



E821 at BNL
 Huge Deviation
 $r = 426 = 1.5 \times 10^{-11}$
 $\sim 3 \times 5 \text{ fb}^{-1}$ loops

$$a_\mu^{\text{SUSY}} \approx (\text{sgn } \mu) \times 130 \times 10^{-11} \left(\frac{100 \text{ GeV}}{m_{\text{SUSY}}} \right)^2 \tan \beta, \quad \tan \beta = \frac{\text{electron mass}}{\text{gaugino mass}}, \quad \tan \beta > 3 \pi^2$$

$$\text{Exp} \rightarrow m_{\text{SUSY}} \simeq (55 - 8) \sqrt{\tan \beta} \text{ GeV}, \quad \mu > 0!$$

iii) $b \rightarrow s\gamma \rightarrow \text{SUSY}$

$$b \xrightarrow{\tilde{H}} s \sim \frac{m_b}{m_{\text{SUSY}}} \tan\beta \cdot (\text{mixing})$$

$\tilde{e} \tilde{e} \tilde{e} \tilde{e}$
 $\gamma \gamma \gamma \gamma$

1.6 σ deviation $\rightarrow \mu > 0$ consistent with $g_\mu - 2$!

Perhaps Precision Measurements are Starting To
See SUSY and it is very close $\sim 100\text{GeV}!!$

An e^+e^- collider with $\sqrt{s} \simeq 200 - 500\text{GeV}$ would come
in handy now!

SUSY is the only game in town!

New $g_\mu - 2$ results later this year $\pm 150 \times 10^{-11} \rightarrow \pm 65 \times 10^{-11}$
(ultimately $\rightarrow \pm 45 \times 10^{-11}$)

$b \rightarrow s\gamma$ Theory Improvements } $\pm 10\%$ each $\rightarrow ?$
BaBar Results }

m_W Tevatron Run II $\rightarrow \pm 15\text{ MeV}$ ($am_2 \rightarrow \pm 2\text{GeV}$)

better $\sin^2 \theta_W^{\text{eff}}$?

Future Giga Z Factory $\rightarrow 50,000$
E158 at SLAC $e^+e^- \rightarrow e^+e^- \rightarrow 10,000$,
running

4. Experimental Frontiers (Direct & Indirect Discovery)

- i) Precision Measurements ($\sin\theta_W, m_W, \beta_2, g-2, APV\dots$)
- ii) FCNC ($b \rightarrow s\gamma, \chi^0, \text{ed.m.} \dots$ proton decay, ν -osc...)
- * iii) High Energy Colliders (Direct Production)

Push on all Fronts

Precision Measurements

TeV Run II $\Delta m_W = \pm 15 \text{ MeV}$, $\Delta m_e = \pm 2 \text{ GeV}$ (LHC?)

Z factory at NLC $10^9 - 10^{10} Z/\text{yr}!$ (6 studies)

$\rightarrow \Delta S_{LR} \sin\theta_W^{\text{eff}} = \pm 0.00002!$, $\Delta T(E \rightarrow L^+L^-) \approx \pm 0.04 \text{ MeV} \dots$

W^+W^- at NLC $\rightarrow \Delta m_W \approx \pm 6 \text{ MeV}$

$t\bar{t}$ at NLC $\rightarrow \Delta m_t \approx 0.2 \text{ GeV}!$

Powerful Measurements

e^+e^- (fixed target at NLC) $\rightarrow \Delta \sin\theta_W \approx \pm 0.000005!$ (A. Kanda)

Rare or Forbidden Reactions: Rare B+K studies, χ^0
(Probe $\rightarrow 3000 \text{ TeV}!$)

Rare B+K studies, χ^0
edm e, μ, H
neutrino osc.
proton decay

$\mu^-N \rightarrow e^-N$ (HECO at BNL) stop $10'' \mu^-/\text{sec.}$, $\mu \rightarrow e \gtrsim 10^{-17} \text{ sec.}$

High Energy Colliders (Most Imperative)

2001 TeV Run II underway ($\sqrt{s} \approx 2\text{TeV}$)

Higgs + Light SUSY Discovery Potential (Hints)

2006 LHC ($\sqrt{s} = 14\text{TeV}$, $\mathcal{L} \approx 10^{34}\text{cm}^{-2}\text{s}^{-1}$ (possible 10^{35} upgrade))

Higgs Discovery + Study Guaranteed!

SUSY Discovery + Study $< 17\text{TeV}$, m_H, m_{H^\pm} } very rich
 Z' , Extra Dim., Heavy Fermions...

2013? TESLA, NLC, JLC e^+e^- Collider $\mathcal{L} \approx 10^{34}\text{cm}^{-2}\text{s}^{-1}$

$\sqrt{s} \approx 500\text{GeV} \rightarrow 17\text{TeV} \rightarrow 1.5\text{TeV} \rightarrow ?$ ($> 30\text{yr}$ program)

low energy option Z factory, W^+W^- ..., $t\bar{t}$, e^+e^- , e fixed to

$e^+e^- \rightarrow ZH$ Thorough Higgs Study $\sqrt{s} \approx 260\text{GeV}$ proto

SUSY studies, dark matter, charginos, sleptons...

e^- Polarization Powerful

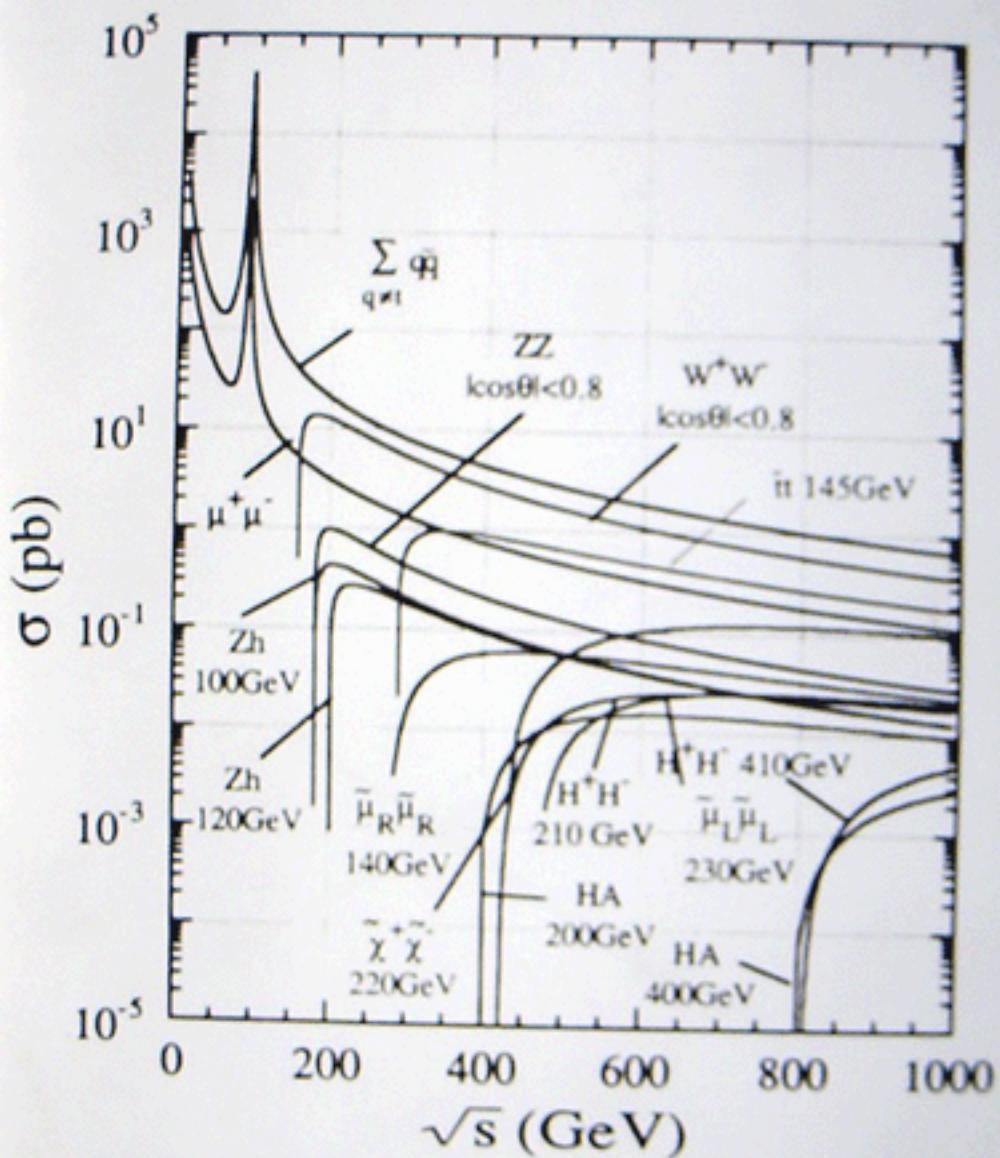
Future: VLHC $\sqrt{s} \approx 100\text{-}200\text{TeV}$, $\mathcal{L} \approx 10^{35}\text{-}10^{36}\text{cm}^{-2}\text{s}^{-1}$

$\mu^+\mu^-$ $\sqrt{s} \gtrsim 3\text{TeV}$

⋮

$\mu\text{SR} \rightarrow \text{CP violation in } \pi^+\pi^-$ { Better Motivated
since SM

From JLC Group



5. Outlook

Exciting Times: Hint of low mass Higgs (115 GeV?)

Hints of low mass SUSY (g_{μ}^2 conform?)

Tevatron Run II → LHC (2006) Great Discovery Pd.

TESLA Proposal (NLC, JLC) Thorough studies: $Z, W, \nu, t\bar{t}, \dots$
H properties, SUSY ...

R&D for future facilities (lifeblood)

Need to also continue: ν -osc, $\beta+K$ studies, $\mu^- N \rightarrow \bar{\nu} N$, $\mu \rightarrow e$,
proton decay, precision meas.

Diversity in the pursuit of Nature is good.

You can't discover if you don't explore!

Have a Good Snowmass